Coordinated Development of Population, Economy and Environment System and Diagnosis of Its Obstacle Factors in Nanjing

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Abstract Promoting the coordinated development of regional population, economy and environment is beneficial to the realization of sustainable development. Based on the construction of evaluation index system of coordinated development of systems, the entropy weight-TOPSIS method and coupling coordination model, the coordinated development degree of population, economy and environment system in Nanjing was measured, and the temporal variation characteristics of each subsystem and their coordinated development degree form 1997 to 2016 were analyzed. The results showed that the development of population, economy system and environment system in Nanjing was generally in a continuous upward trend. Among them, the economy system developed fastest. The coordinated development degree of population, economy system and environment system in Nanjing was constantly increasing but still at a low level; the degree was only in the primary coordination phase, and its type was environment lagging. The economy subsystem and environment subsystem were important factors restricting the development of population, economy and environment in Nanjing, and the main obstacle factor was the production of industrial solid waste. The results above can provide a scientific basis for promoting the coordinated development of population, economy and environment system in Nanjing and achieving regional sustainable development.

Key words Population, economy and environment system; Coordinated development degree of systems; Entropy weight-TOPSIS; Obstacle factors; Nanjing

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Sustainable development is a development model based on the coordination and common development of population, economy, resources and the environment, and its theory is widely recognized by countries all over the world[1]. With the rapid development of the social economy, the contradiction between population, economy and environment has intensified. Population security is the foundation for stable economic development. Promoting coordinated development among population, economy and environment is an important way to achieve regional sustainable development.

At present, many scholars have adopted methods such as TOPSIS method[2], principal component analysis[3], and analytic hierarchy process[4] to calculate the comprehensive benefit of population and economy system[5], 3E system (economy – environment – energy system)[6], population, economy and society system[7], and population, economy and environment system[8], and used coupling coordination models[9], regression models[6] and other models to analyze the coordinated development between systems. In the research on the coordinated development of population – economy – environment system, the spatial and temporal evolution of the coordinated development of the system is mainly analyzed[10 – 11]. In many related studies today, the selection of indicators for environmental pollution mainly considers the impact of industrial pollution, and rarely consider environmental pollution from the use of chemical fertilizers and pesticides, which will have a certain impact on the calculation of comprehensive benefit of environment system.

In this paper, based on the entropy weight-TOPSIS method and a coupling coordination model, the coordination degree of population, economy and environment system in Nanjing from 1997 to 2016 was calculated, and its temporal variation characteristics were analyzed. Moreover, the obstacle factors restricting the development of population, economy and environment system in Nanjing were analyzed to provide important reference for the regional sustainable development of China.

1 Data sources and research methods

1.1 Data sources The data used in this study were from Nanjing Statistical Yearbook and *Jiangsu Statistical Yearbook* during 1998 – 2017, *China City Statistical Yearbook* during 1998 – 2016, and statistical bulletin of national economic and social development in Nanjing in 2016. The coordination degree of population, economy and environment system in Nanjing from 1997 to 2016 was calculated firstly, and then its temporal changes and characteristics were analyzed. Finally, the diagnosis of the obstacle factors restricting the coordinated development was conducted.

1.2 Research methods

1.2.1 Construction of evaluation indicator system. According

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to previous studies[4,12-13], the evaluation indicator system of population, economy and environment system in Nanjing was constructed, and 26 indicators were selected (Table 1). Among them, the population subsystem reflects the employment situation, distribution, gender structure and education quality of population. The economy subsystem reflects economic quality. The environment subsystem reflects environmental construction, environmental pollution, and environmental governance.

Table 1 Evaluation system for the coordinated development of population, economy and environment system in Nanjing

Goal layer	Criterion layer	Indicator layer	Unit	Code	Weight	Property
Population subsystem (0.253)	Population size	Total population	$\times 10^4$	X_1	0.150	+
		Number of employees	$\times 10^4$	X_2	0.118	+
		Natural growth rate of population	‰	X_3	0.160	+
	Population structure	Proportion of urban population to rural population	–	X_4	0.122	+
		Sex ratio of males to females	–	X_5	0.148	+
		Unemployment rate of urban population	%	X_6	0.153	–
		Number of students in ordinary institutions of higher education (including graduate students)	$\times 10^4$	X_7	0.149	+
Economy subsystem (0.367)	Economic gross	GDP	$\times 10^8$ yuan	X_8	0.125	+
		Output value of the primary industry	$\times 10^8$ yuan	X_9	0.132	+
		Output value of the secondary industry	$\times 10^8$ yuan	X_{10}	0.131	+
		Output value of the tertiary industry	$\times 10^8$ yuan	X_{11}	0.120	+
		Total investment in fixed assets of the whole society	$\times 10^8$ yuan	X_{12}	0.119	+
		Total financial revenue	$\times 10^8$ yuan	X_{13}	0.132	+
	Economic quality	GDP per capita	yuan	X_{14}	0.129	+
		Household consumption level	yuan	X_{15}	0.112	+
Environment subsystem (0.380)	Environmental construction	Urban green space area	hm^2	X_{16}	0.092	+
		Green cover area	hm^2	X_{17}	0.091	+
	Environmental pollution	Total discharge of industrial wastewater	$\times 10^8$ t	X_{18}	0.083	–
		Total emission of industrial waste gas	$\times 10^8\ m^3$	X_{19}	0.100	–
		Production of industrial solid waste	$\times 10^4$ t	X_{20}	0.104	–
		Emission of industrial SO_2	$\times 10^4$ t	X_{21}	0.110	–
		Usage of pesticides per hectare of cultivated land	t/hm^2	X_{22}	0.082	–
		Usage of fertilizer per hectare of cultivated land	t/hm^2	X_{23}	0.082	–
	Environmental governance	Transportation amount of domestic garbage	$\times 10^4$ t	X_{24}	0.081	+
		Treatment rate of sewage	%	X_{25}	0.103	+
		Volume of saved water	$\times 10^4\ m^3$	X_{26}	0.071	+

1.2.2 Data processing. The indicators in the evaluation indicator system are dimensionlessly processed, and then the entropy weight-TOPSIS method was used to calculate the entropy according to the variation degree of the indicators. The entropy of each indicator was used to weight the indicator[14]. The entropy method was revised according to the results of Huang Peng *et al.*[15], and the weight of each indicator is shown in Table 1. The technique of approximating the ideal solution was used to determine the order of the evaluation objects, a virtual optimal solution and worst solution were set to solve the relative proximity of each scheme to the ideal solution, and the order of the schemes was determined by relative closeness[16].

1.2.3 Evaluation of coordination degree of population, economy, and environment system. The coordination degree of development of population, economy and environment system in Nanjing was calculated as follows:

$$C = \left[\frac{F_1 \times F_2 \times F_3}{(F_1 + F_2 + F_3)^3} \right]^{\frac{1}{3}}$$

$$F = W_1 F_1 + W_2 F_2 + W_3 F_3$$

$$D = (C \times F)^{\frac{1}{2}}$$

where C is the coupling degree of population, economy and environment system in Nanjing; F is the comprehensive score of development of population, economic and environment system in Nanjing; D is the coordination degree of development of population, economy and environment system in Nanjing. W_1, W_2 and W_3 are the weight of the population subsystem, economy subsystem and environment subsystem determined by the entropy method, equaling 0.253, 0.367 and 0.380 respectively.

1.2.4 Diagnosis of obstacle factors. In this paper, "contribution rate of factors", "deviation degree of indicators" and "obstacle degree" were introduced to construct an obstacle model to diagnose the obstacle factors of population, economy and environment system in Nanjing[17-18]:

$$q_j = W_i \times W_{ij}$$

$$Z_{ij} = 1 - x'_{ij}$$

$$S_{ij} = \frac{q_j \times Z_{ij}}{\sum_{j=1}^{n} q_j \times Z_{ij}} \times 100\%$$

$$S_j = \frac{\sum_{i=1}^{m} S_{ij}}{m}$$

where q_j is the contribution rate of the j^{th} indicator, namely the weight of the j^{th} indicator to the overall goal (population, economy and environment system); W_i is the weight of the population subsystem, economy subsystem and environment subsystem to the overall goal; W_{ij} is the weight of each indicator to its subsystem; Z_{ij} is the deviation degree of each indicator, namely the difference between the actual value and the optimal value of each indicator after standardization; X_{ij} is the value of a standardized indicator; S_{ij} is the obstacle degree of the j^{th} indicator in the i^{th} year, indicating the influence degree of the indicator on the overall goal in the i^{th} year; S_j is the annual average obstacle degree of the j^{th} indicator; n is the number of the indicators (here $n=26$); m is the number of years (here $m=20$).

2 Results and analysis

2.1 Temporal variation characteristics of coordinated development of population, economy and environment system in Nanjing It can be seen from Table 2 that the comprehensive score, coupling degree and coordination degree of development of population, economy and environment system in Nanjing were continuously rising from 1997 to 2016. The coordination degree of the systems ranged from 0.105 to 0.509. According to the classification system and discriminant standard of coupling coordination of regional population, economy and environment determined by Wang Chunping *et al.*[11] (Table 3), it can be concluded that there was a serious imbalance between the systems in Nanjing from 1997 to 1998, and the type was economy lagging; there was a moderate imbalance between the systems during 1999 – 2003, and the type was also economy lagging; there was a slight imbalance between the systems from 2004 to 2008, and the type was also economy lagging; the systems were on the verge of imbalance from 2009 to 2015, and the type changed from economy lagging to environment lagging; in 2016, it reached primary coordination, and the type was environment lagging. It can be seen that although population, economy and environment systems in Nanjing tended to increase on the whole in the past 20 years, the coordination degree between the three systems was relatively poor. The three systems were coordinated reluctantly until 2016.

Table 2 Comprehensive score, coupling degree and coordination degree of development of population, economy and environment system in Nanjing from 1997 to 2016

Year	Comprehensive score	Coupling degree	Coordination degree	Year	Comprehensive score	Coupling degree	Coordination degree
1997	0.247	0.044	0.105	2007	0.448	0.317	0.377
1998	0.223	0.140	0.177	2008	0.486	0.321	0.395
1999	0.240	0.176	0.205	2009	0.517	0.325	0.410
2000	0.256	0.209	0.232	2010	0.552	0.331	0.427
2001	0.269	0.233	0.251	2011	0.603	0.333	0.448
2002	0.301	0.248	0.273	2012	0.643	0.333	0.463
2003	0.317	0.274	0.295	2013	0.671	0.332	0.472
2004	0.349	0.290	0.318	2014	0.710	0.331	0.485
2005	0.369	0.308	0.337	2015	0.749	0.329	0.496
2006	0.403	0.308	0.352	2016	0.791	0.327	0.509

Table 3 Classification system and discriminant standard of coupling coordination of population, economy and environment system in Nanjing

Interval	*D*	Class	Type
Coordination interval	(0.90,1.00]	Very good coordination	When $F_{min}=\min\{F_1, F_2, F_3\}$, it is F_{min} lagging type. For example, when $F_{min}=F_1$, it is population lagging type. When $F_1=F_2=F_3$, it is population-economy-environment synchronization type.
	(0.80,0.90]	Good coordination	
	(0.70,0.80]	Moderate coordination	
	(0.60,0.70]	Reluctant coordination	
Transition interval	(0.50,0.60]	Primary coordination	
	(0.40,0.50]	Being on the verge of imbalance	
Imbalance interval	(0.30,0.40]	Slight imbalance	
	(0.20,0.30]	Moderate imbalance	
	(0.10,0.20]	Serious imbalance	
	(0.00,0.10]	Extreme imbalance	

2.2 Diagnosis of obstacle factors restricting the coordinated development of population, economy and environment system in Nanjing In terms of annual average obstacle degree (Table 4), the production of industrial solid waste ranked firstly, and the sex ratio of males to females and total emission of industrial waste gas ranked secondly and thirdly respectively, followed by total fiscal revenue, output value of the primary industry, emission of industrial SO_2, household consumption level, GDP per capita, output value of the tertiary industry, and GDP. Here the top ten indicators (annual average obstacle degree ≥ 5%) were selected as the main obstacle factors. Among them, the population subsystem had one indicator, and the economy subsystem had six indicators, while the environment subsystem contained three indicators.

Table 4 Order of annual average obstacle factors of population, economy and environment system in Nanjing

Indicator	Annual average obstacle degree//%	Order	Indicator	Annual average obstacle degree//%	Order
X_{20}	5.79	1	X_{12}	4.12	14
X_5	5.74	2	X_{26}	3.21	15
X_{19}	5.48	3	X_{24}	3.02	16
X_{13}	5.43	4	X_4	2.68	17
X_9	5.40	5	X_{23}	2.23	18
X_{21}	5.40	6	X_2	2.20	19
X_{15}	5.23	7	X_1	2.18	20
X_{14}	5.20	8	X_{22}	2.17	21
X_{11}	5.17	9	X_{18}	2.16	22
X_8	5.14	10	X_{25}	2.10	23
X_{10}	4.93	11	X_7	1.99	24
X_6	4.64	12	X_{17}	1.95	25
X_3	4.59	13	X_{16}	1.85	26

2.2.1 Diagnosis of main obstacle factors. Seen from annual average obstacle degree, the production of industrial solid waste was the primary obstacle factor. The production of industrial solid waste continued to increase over the past two decades, rising by 268.6% from 1997 to 2016. Moreover, the comprehensive utilization rate of industrial solid waste decreased in recent years, increasing the pressure on environment system. The imbalance of the sex ratio was not conducive to social stability, leading to aging and population shrinking and threatening population safety. The total emission of industrial waste gas continued to increase from 1997 to 2015, and the first negative growth appeared in 2016, indicating that the treatment of waste gas has begun to bear fruit. The discharge of waste gas causes air pollution, damages ecological environment, and affects human health.

2.2.2 Diagnosis of classified obstacle factors. Seen from the interannual variation of obstacle degree of the main obstacle factors (Table 5), the top three obstacle factors during 1997 – 2006 were the indicators in the economic subsystem, namely the output value of the primary industry, total fiscal revenue and GDP per capita. From 2007 to 2009, the output value of the tertiary industry and household consumption level in the economic subsystem also became the main obstacle factors. In 2010, the emission of industrial solid waste became the primary obstacle factor, followed by household consumption level and the output value of the primary industry. Since 2011, the top three obstacle factors were the production of industrial solid waste and emission of industrial waste gas in the environment subsystem and the gender ratio of males and females in the population subsystem. The interannual variation trend of the main obstacle factors was consistent with the change of the coupling coordination type of population, economy and environment system in Nanjing. When it was economy lagging type, the main obstacle factors were mainly indicators of the economy subsystem; when it was environment lagging type, the main obstacle factors were mainly indicators of the environment subsystem.

Table 5 Order of main obstacle factors of population, economy and environment system in Nanjing

Year	I	II	III	Year	I	II	III
1997	X_9	X_{13}	X_{14}	2007	X_{13}	X_{14}	X_{15}
1998	X_9	X_{13}	X_{14}	2008	X_{13}	X_{14}	X_{11}
1999	X_9	X_{13}	X_{14}	2009	X_{15}	X_{14}	X_{11}
2000	X_{13}	X_9	X_{14}	2010	X_{20}	X_{15}	X_9
2001	X_{13}	X_9	X_{14}	2011	X_{20}	X_{19}	X_5
2002	X_9	X_{13}	X_{14}	2012	X_5	X_{20}	X_{19}
2003	X_9	X_{13}	X_{14}	2013	X_{19}	X_5	X_{20}
2004	X_9	X_{13}	X_{14}	2014	X_{19}	X_5	X_{20}
2005	X_{13}	X_{14}	X_8	2015	X_{19}	X_5	X_{20}
2006	X_9	X_{14}	X_{13}	2016	X_{20}	X_5	X_{19}

3 Conclusions

Based on the construction of the evaluation system, the entropy weight-TOPSIS method and system coupling coordination model, the coordinated development of population, economy and environment system in Nanjing and the temporal changes of each subsystem development during 1997 – 2016 were analyzed. The results showed that the development of population, economy and environment system in Nanjing were all in a continuous upward trend from 1997 to 2016, among which the economy system developed fastest. The coordination degree of development of population, economy and environment system in Nanjing was rising, but still at a low level. After 20 years of development, it had risen from serious imbalance to primary coordination, and it changed from economy lagging to environment lagging in 2011.

In order to further explore the obstacle factors restricting the coordinated development of population, economy and environment system in Nanjing, the obstacle degree model was calculated. The results showed that the main obstacle factors were the output value of the primary industry, total fiscal revenue and GDP per capita in the economy system before 2010, and changed to the production of industrial solid waste and emission of industrial waste gas in the environment subsystem since 2011. The change of the obstacle factors was consistent with the type change of the coordination degree of the system development. According to the annual average rate of change of the obstacle factors, the main obstacle factor was the production of industrial solid waste. The economy system and environment system were important factors restricting the development of population, economy and environment in Nanjing.

4 Discussion

To promote the coordinated development of population, economy and environment system in Nanjing to achieve sustainable development, the following two suggestions are proposed as follows.

(1) "Saving is the source of the first energy resources", which is the consensus of the current international community. Over the years, the Chinese government has also placed energy and resource conservation at the top of China's energy policy. Since General Secretary Xi Jinping inspected the Yangtze River Economic Belt, Nanjing's current most important task is to attach great importance to resource and energy conservation, continue to vigorously promote energy conservation and consumption reduction, vigorously develop economic development models that are in harmony with the environment, and achieve efficient use of resources and harmless emission of waste, and reduce the pressure on the environment system from economic development.

(2) From the perspective of public opinion, it is necessary to vigorously publicize for a long time to form a trend and consensus on low-carbon life in the whole society, especially to promote the development of low-carbon agriculture, and reduce the use of pesticides and fertilizers to make agriculture develop towards low pollution. Meanwhile, it is necessary to insist on deepening reform, continue to adjust economic structure, optimize the industrial layout of Nanjing City, and promote the upgrading of energy-consuming equipment in high-energy-consuming enterprises from the technical level to effectively reduce carbon emissions.

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